

Single bunch instability and impedance issues



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Collaborators

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Outline

Longitudinal Wake Potentials

- calculations (1994 report, updated by Zhang)

- measurements with beam

Longitudinal stability

Transverse stability

Transverse Wake Potentials

- calculations (1994 report, + Zhang)

- bench measurements (Davino,Hahn)

Comparison with theory

Longitudinal impedance courtesy S.Y. Zhang

Space charge
not included.

At injection

$$\left. \frac{Z}{n} \right|_{sc} \approx 10\Omega$$

Similar to 94
report.

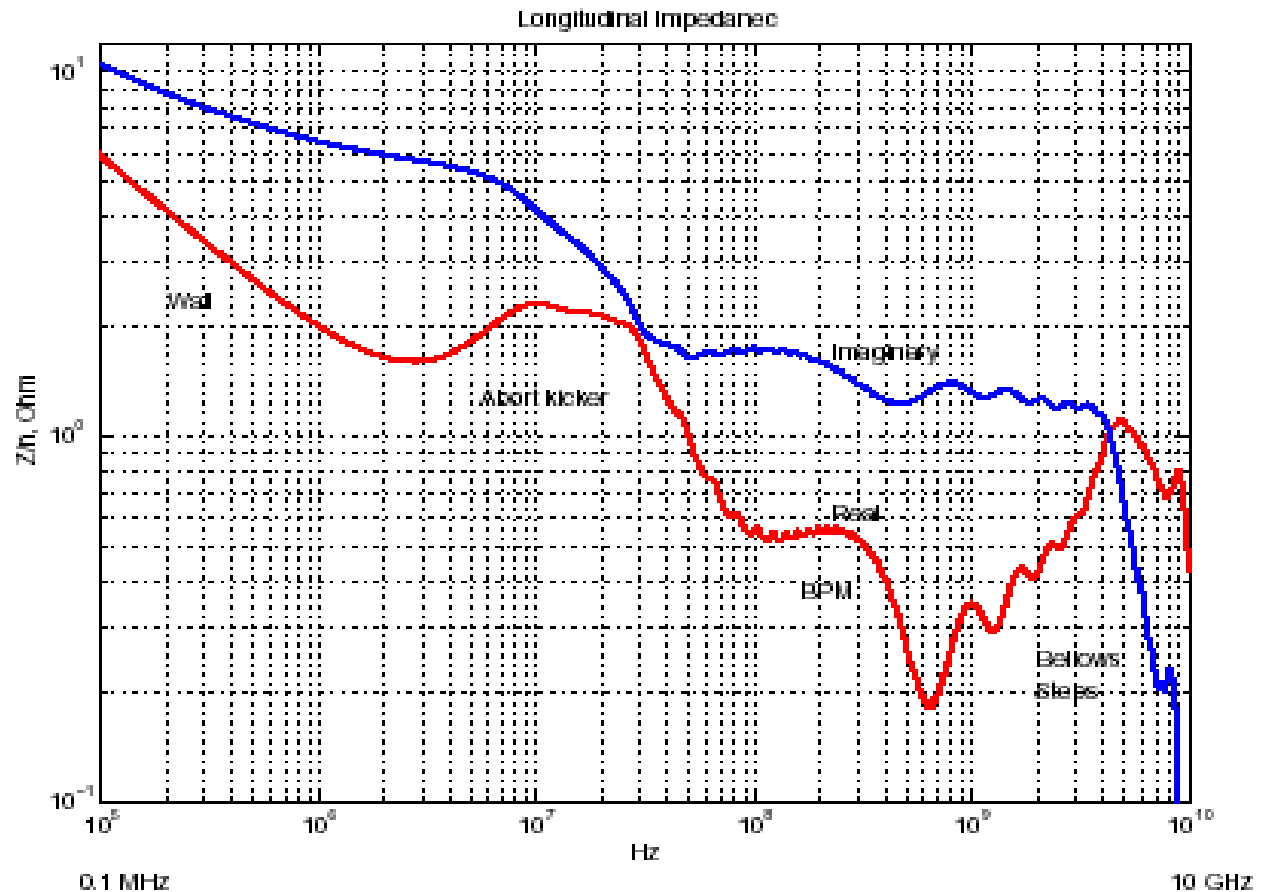
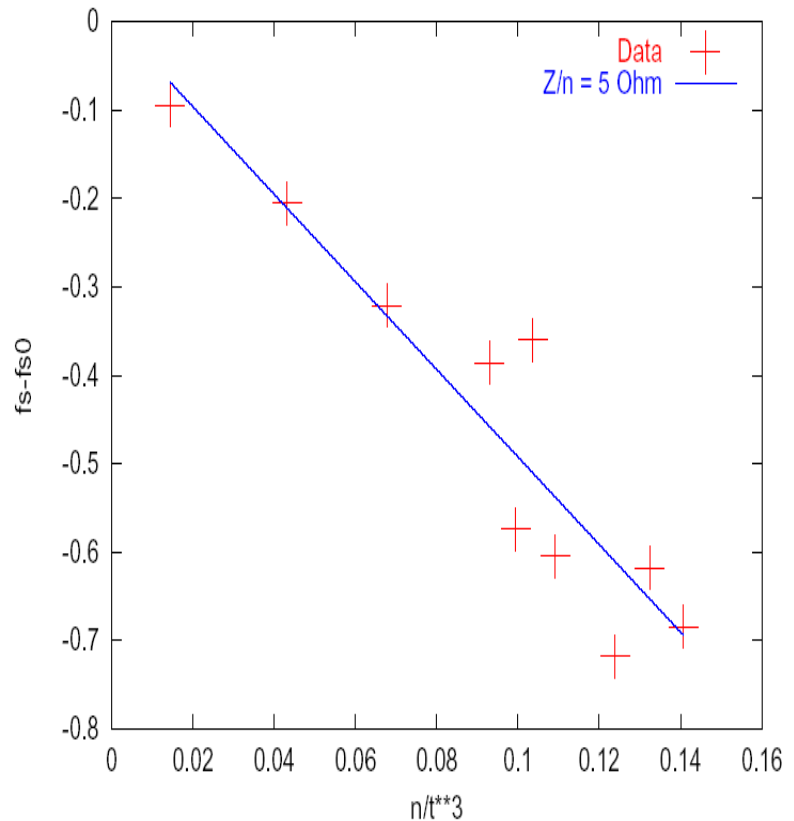
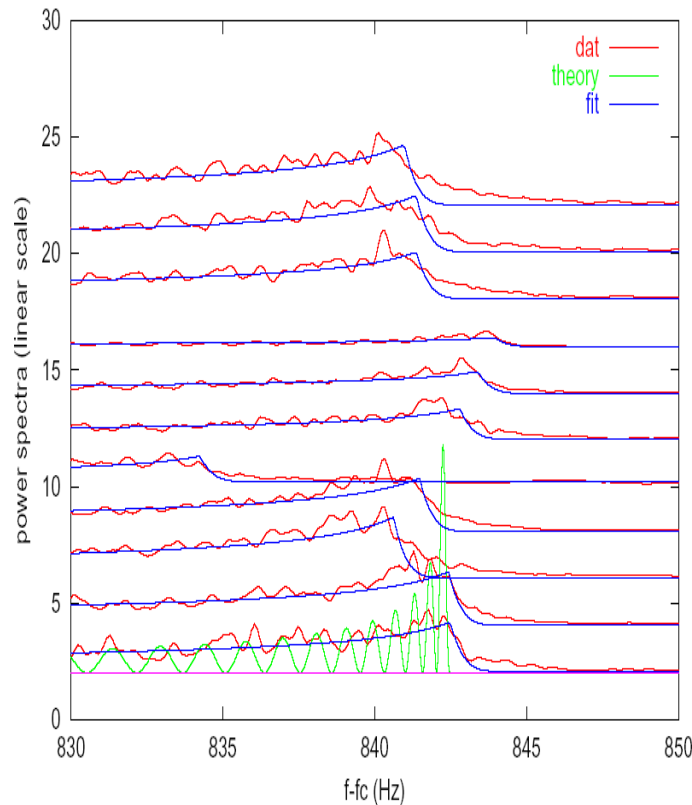


Figure 1: RHIC Longitudinal Impedance.

Longitudinal impedance measured at Au injection

Used 2.7 GHz Schottky monitor to measure the small amplitude incoherent synchrotron frequency as a function of bunch length and intensity. Expected $Z/n \approx 8$ Ohm.



Transition simulations

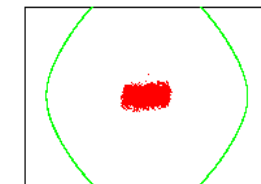
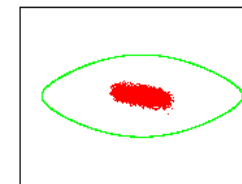
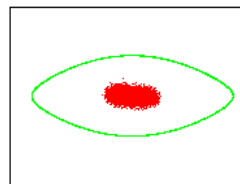
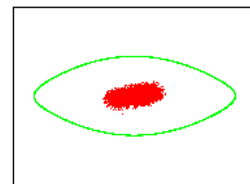
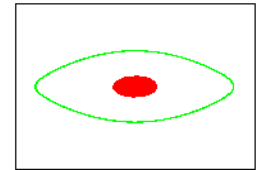
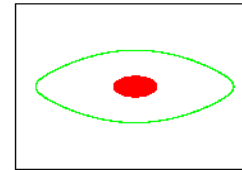
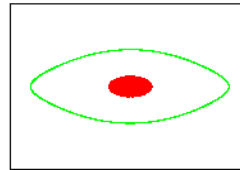
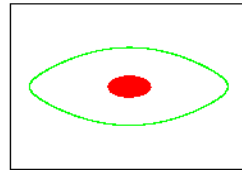
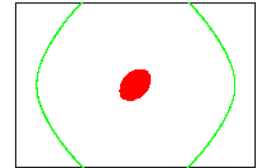
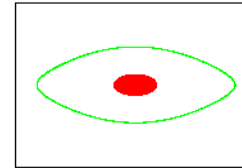
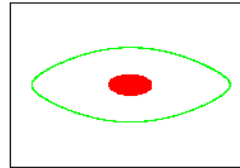
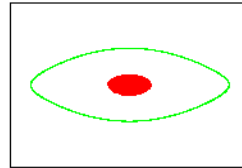
0.4 second simulation

full $\Delta\gamma t = 1$

1.e9 ions

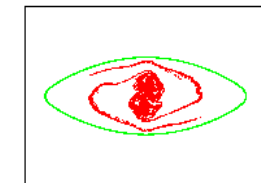
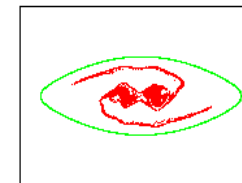
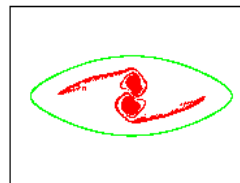
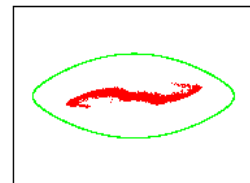
0.56 eV-s/nucleon

$Z/n = 0$



$Z/n = 0.5$ Ohm

(Modeled, not
Measured, value)



Behavior of a single proton bunch after 40 min

Single particle dynamics gives

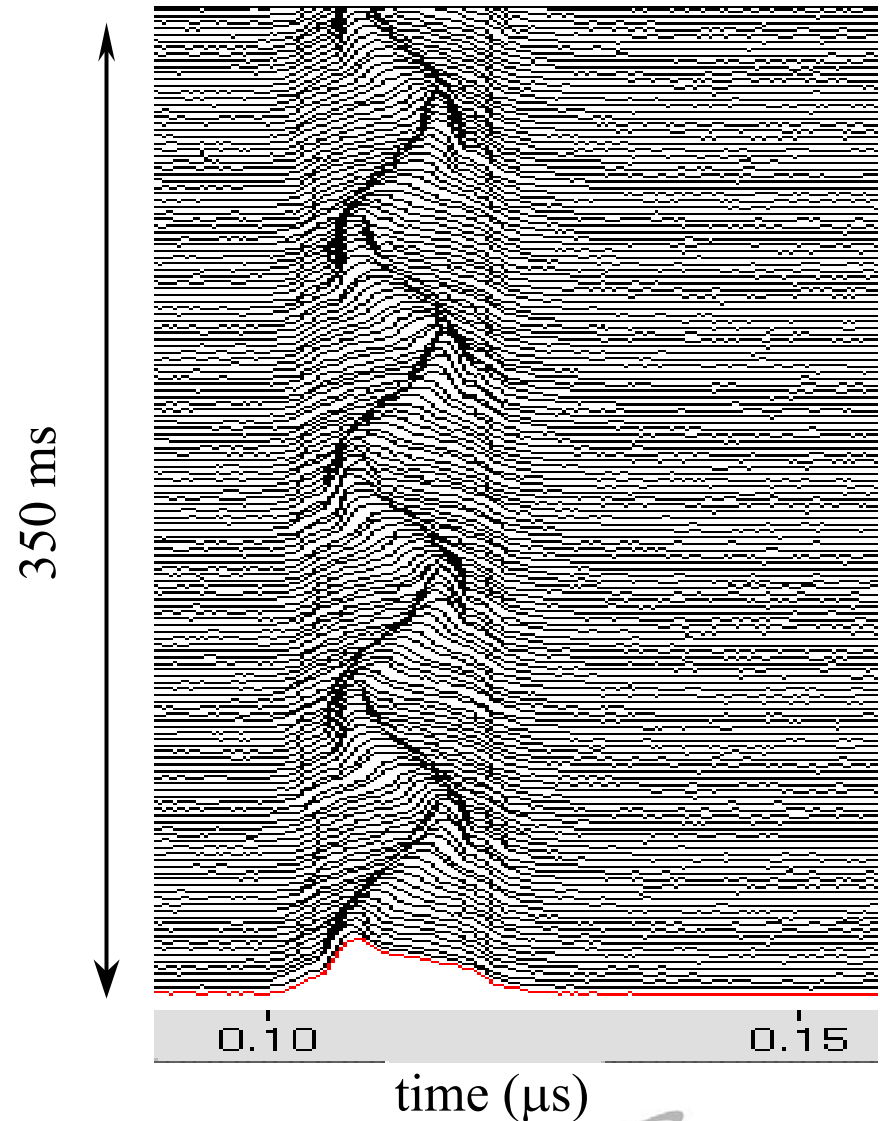
$$\delta\omega_s = \omega_s(0)(\varphi_+^2 - \varphi_-^2)/16$$

This is of order 10/s so there are collective effects.

Threshold for coherent dipole oscillations (Zotter)

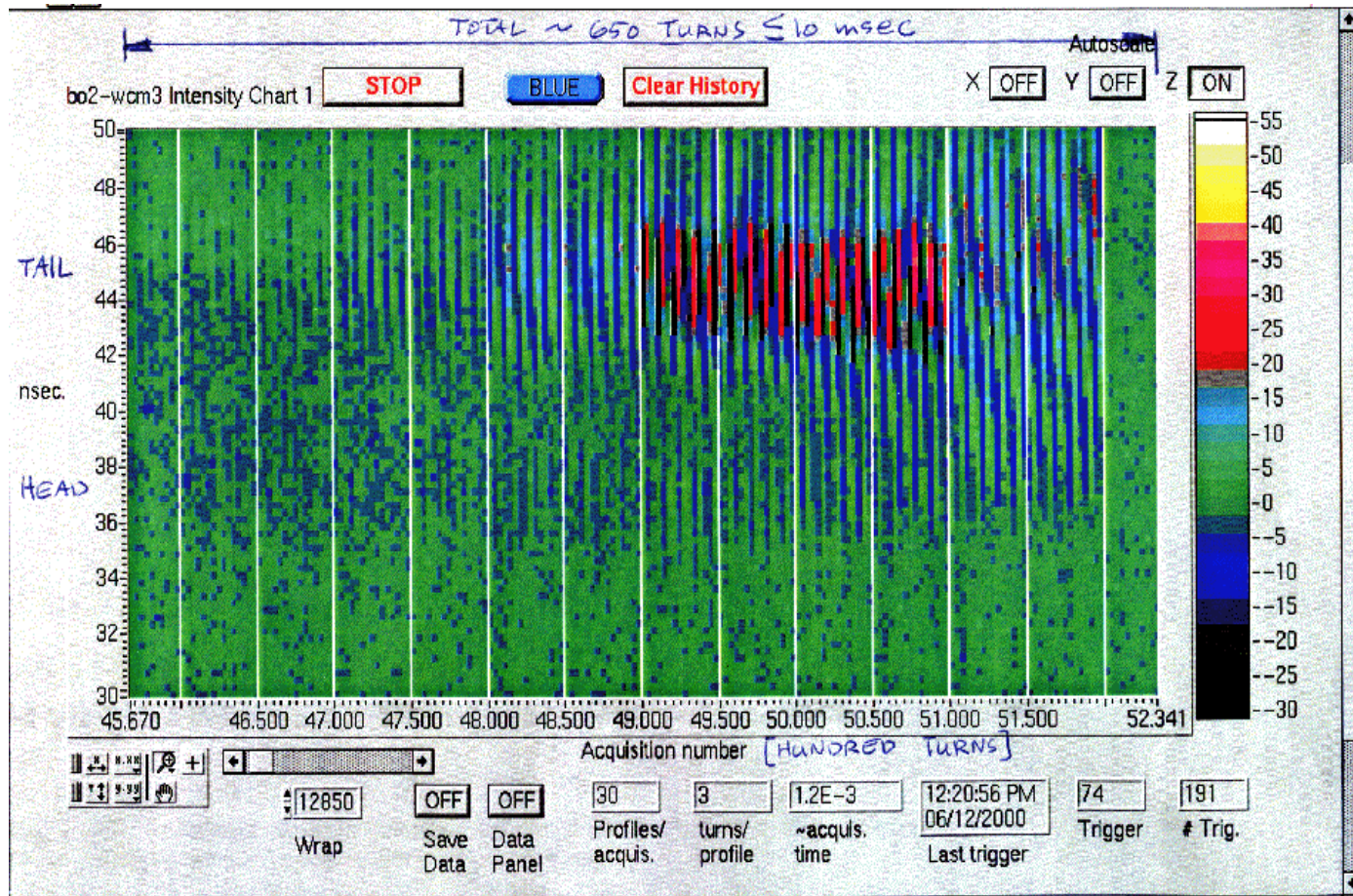
$$0.1 \approx \frac{Q_9}{\tau_9^5} \frac{1}{V_6} \left| \frac{Z}{n} \right|_1$$

Need a few Ohms, but 5th power and impedance details need attention. Use of independent impedance measurements is uncommon.



Fast transverse instability near transition

Half beam lost in $O(10 \text{ ms})$, near chromaticity=0, octupoles stabilize



Characteristics of fast loss

WCM measurement show beam loss over 10 ms.

Chromaticity needs to change sign near transition and instability generally hits when chromaticity is near zero.

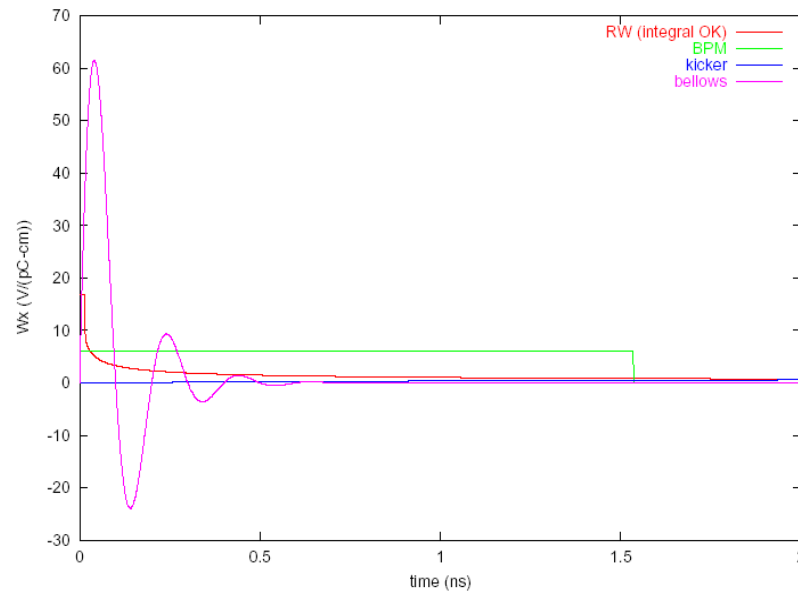
Octupoles stabilize but requires trade-off with dynamic aperture.

Can this be explained with known transverse wake potentials?

Wake potential is the Green function for the collective transverse momentum kick.

On a given bunch passage the kick is given by

$$c\Delta P_x(t) = q \int_0^t W_x(t-t_1) \bar{x}(t_1) I(t_1) dt_1$$



Preliminary instability studies

$$\frac{d^2 x}{d\theta^2} = -Q_x^2 (\varphi') x + C_{sc} \lambda(\theta, t) (x - \langle x(\theta, t) \rangle) + F_{wall}(\theta, t)$$

$$\frac{d^2 \varphi}{d\theta^2} = -Q_s^2 \varphi$$

$$F_{wall}(\theta, t) = \int_0^t \lambda(\theta, t_1) \langle x(\theta, t_1) \rangle W_x(t - t_1) dt_1$$

$dQ_{sc}/Q_s \approx 40$

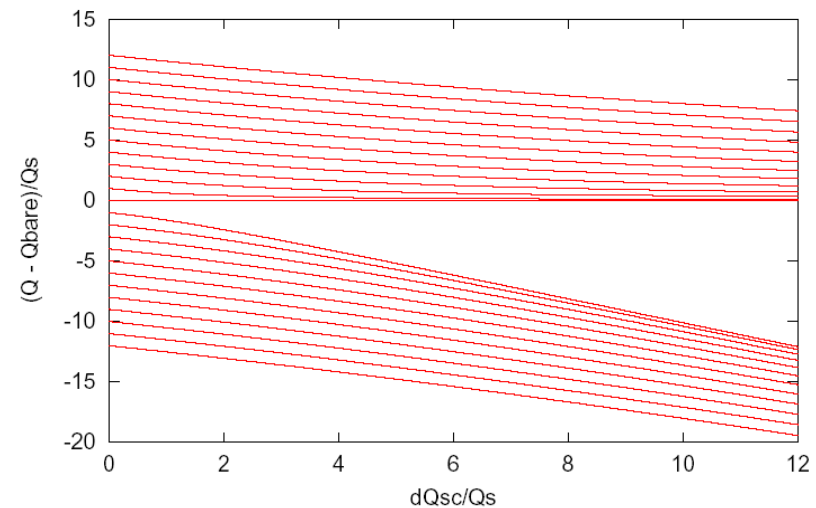
Wake approximated
as a sum of poles (speed)

$3.e4$ macro-particles

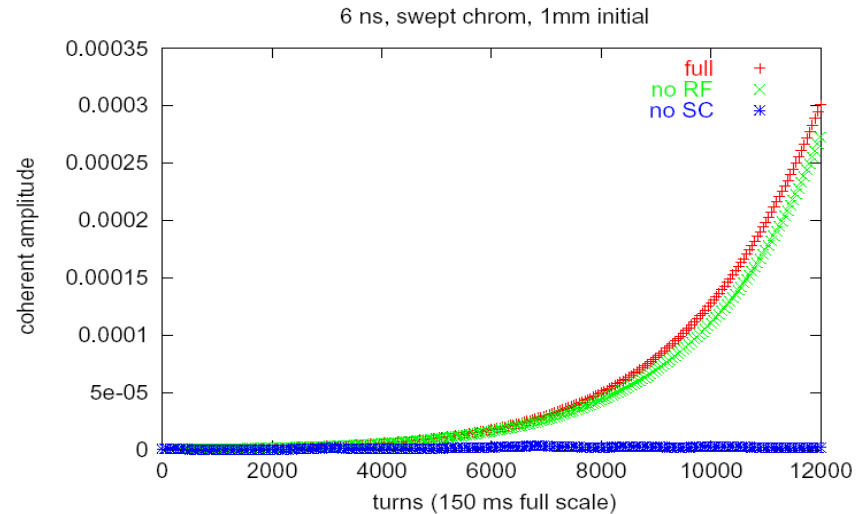
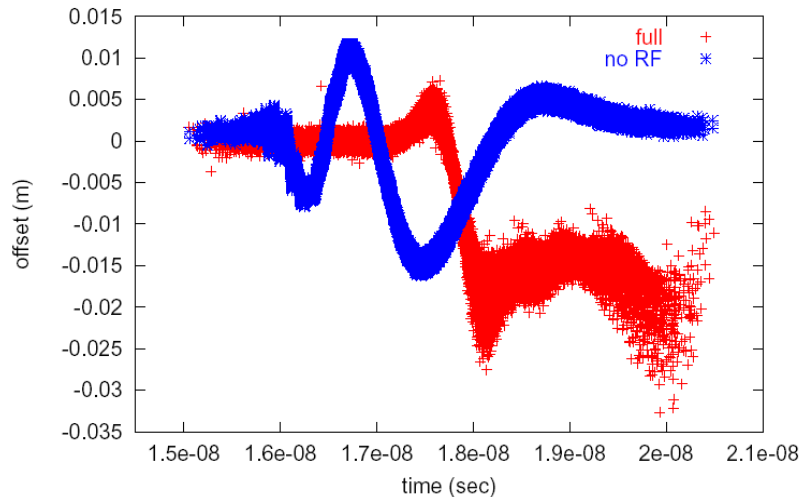
Neglect $2Q_x + mQ_s = k$

resonances

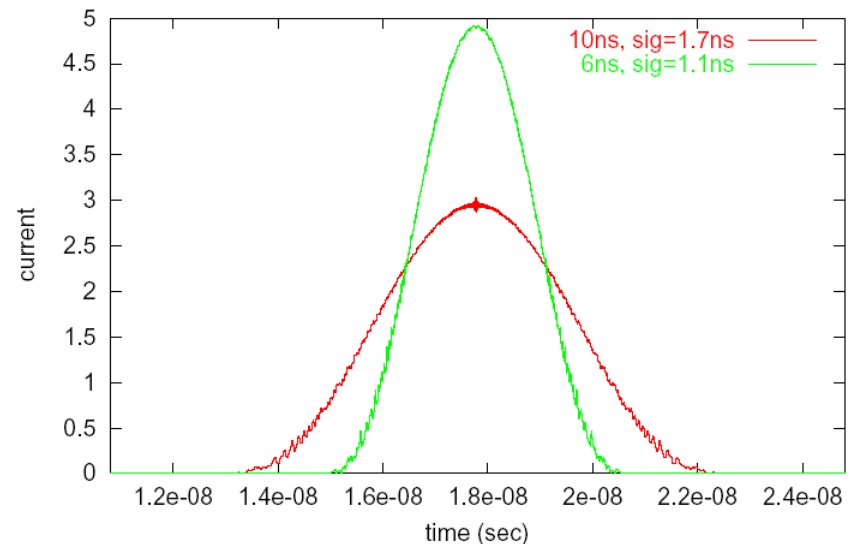
Adequate benchmarking
would give a design tool.



Known wall wakes give somewhat slower growth



Last turn with 1×10^9 ions and
6 ns bunch length shown
The 1 mm initial offset is significant
Full model grows from 1.5 to 2 cm in
25 ms
BPM sum and diff mountain range
triggered at γt would clarify



Summary

Both longitudinal and transverse single bunch effects are major considerations for high intensity operations.

Better measurements of both the transverse and longitudinal wake potentials will improve understanding and strategies.

Quadrupole (bunch shape) damper for longitudinal at transition?

Acquiring better data for the fast loss after transition is a priority. This is largely a triggering/data storage issue.

Once a reasonable model is obtained, various damping strategies such as octupoles, chromaticity jumps and quadrupole cavities can be explored using simulations ala TMCI in LEP.

“Clean living”, such as closed orbits through the center of the γ jump quads, may help transverse (smaller instability seeds).